Governing large-scale social-ecological systems: Lessons from five cases

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Abstract: This paper compares lessons drawn from five case studies of large scale governance of common-pool resources: management of forests in Indonesia,

the Great Barrier Reef in Australia, the Rhine River in western Europe, the Ozone layer (i.e. the Montreal Protocol), and the Atlantic Bluefin Tuna (i.e. the International Convention on the Conservation of Atlantic Tuna). The goal is to assess the applicability of Ostrom's design principles for sustainable resource governance to large scale systems, as well as to examine other important variables that may determine success in large scale systems. While we find support for some of Ostrom's design principles (boundaries, monitoring, sanctions, fit to conditions, and conflict resolution mechanisms are all supported), other principles have only moderate to weak support. In particular, recognition of rights to organize and the accountability of monitors to resource users were not supported. We argue that these differences are the result of differences between small and large scale systems. At large scales, other kinds of political dynamics, including the role of scientists and civil society organizations, appear to play key roles. Other variables emphasized in common-pool resource studies, such as levels of dependence on resources, group size, heterogeneity, disturbances, and resource characteristics also receive mixed support, pointing to the need to reinterpret the meaning of common-pool resource theories in order for them to be applicable at larger scales.

Keywords: Common-pool resource theory, design principles, forests, fisheries, marine protected areas, pollution, scale

1. Introduction

Common pool resource (CPR) theory emerged in response to arguments that collective action for mutually beneficial goals, including resource management, is unfeasible in large groups (Olson 1965) without coercion (Hardin 1968) or private property rights (Gordon 1954). CPR theory explores a wider set of conditions that can foster collective action. Ostrom (1990) identified eight "design principles" which are key conditions that facilitate successful collective action for resource governance. These principles have received strong support from subsequent research on local resource management, yet it remains unclear

whether they apply to larger-scale environmental governance dilemmas (Cox et al. 2010).

The purpose of this paper is to use the evidence from the five case studies presented in this special issue to generate a set of initial hypotheses and directions for further research on the applicability of the design principles and other core components of the CPR literature to large-scale social-ecological systems. To do so, we first evaluate the degree to which each of the design principles played an important role in the successes and failures of the five cases. We also evaluate six other variables identified in the literature and discussed within each case paper. This comparison provides the basis for generating a series of questions and propositions for future investigation. We do not systematically compare all the variables identified in the case studies, nor do we conduct a formal comparison of cases, but rather focus on comparing the lessons drawn from the five case study papers. Thus our study should be seen as highlighting some initial research opportunities. The intention of the social-ecological systems meta-analysis database (SESMAD) (described by Cox 2014) is to provide a basis for larger-n comparative studies of large-scale social-ecological systems, and the questions and propositions generated from these five case studies thus serve as a starting point for future analyses.

The five case studies are: global regulation of ozone-depleting substances in the Montreal Protocol (Epstein et al. 2014a); management of Atlantic Bluefin tuna, an open ocean fishery (Epstein et al. 2014b); mitigation of trans-boundary water pollution in the Rhine region (Villamayor-Tomas et al. 2014); national forest management in Indonesia (Fleischman et al. 2014), and; a regional marine protected area network, the Great Barrier Reef, Australia (Evans et al. 2014). Summaries of these cases are available in Table 1, as well as in the papers devoted to the cases. These cases were selected for initial development of the SESMAD database for three reasons: 1) their diversity i.e. they represent examples of global, regional, and trans-boundary governance of different resources (extraction and pollution) in different contexts; 2) availability of literature on the cases, and; 3) the authors' familiarity with the cases. Given the small number of case studies, the conclusions of our comparison are the result of a set of "heuristic" cases used to explore and develop hypotheses, rather than a strong test of theory (George and Bennett 2005). More robust sampling designs are being developed for further addition of cases to the database. Further information on the case studies is provided in Table 1.

2. Methods

The goal of the SESMAD project, of which the case analysis presented here is a part, is to provide a framework for the analytic comparison of case studies of large-scale social-ecological systems. The SESMAD database, which is further

Table 1: Summary of the case studies.

The Great Barrier Reef Marine Park in Australia

The Great Barrier Reef Marine Park (GBRMP) is commonly portrayed as the world's best implementation of marine protected area design theory (Fernandes et al. 2005). At about 345,000 km^2, the GBRMP is one of the largest marine protected areas. It is one of the seven natural wonders of the world, and a globally important marine ecosystem with vast environmental, cultural, social and economic value (McCook et al. 2010). It encompasses seventy bioregions, represents around ten percent of all coral reefs in the world, and is home to more than 1600 fish species, 500 coral species, 40 mangrove species, and 27 vulnerable or endangered species (Great Barrier Reef Marine Park Authority 2009).

While the GBRMP is large and complex, it can be interpreted as having several key social-ecological components (Evans et al. 2014). In 1975 the GBRMP was established with an Act – the governance system – that has the management authority reporting directly to the prime minister's office. Management is shared by two key actor groups – those that manage the reef (i.e. spatial management), and fisheries managers. While there are many different uses of the GBRMP, there are two user groups that have an effect on the GBRMP at the scale of the whole park – commercial and recreational fishers. The case was coded as having two main types of resources: fish that are targeted by fisheries, and coral reefs using a proxy of coral cover. The GBRMP was re-zoned in 2004, resulting in an increase in no-fishing zones from 4% to 34%, with separate but simultaneous changes in fisheries management. These changes have resulted in increases in targeted fish, yet coral cover continues to decline due to external factors (climate change related stressors and land-based influences).

International Commission for the Conservation of Atlantic Tunas

The International Commission on the Conservation of Atlantic Tuna (ICCAT) regulates the use of Atlantic Bluefin Tuna (ABFT), as well as other species, in a large-scale oceanic commons. ABFT (*Thunnus, thynnus)*, is a large-bodied fish species that inhabit much of the North Atlantic Ocean and Mediterranean Sea, and is particularly valuable in the lucrative Japanese sashimi market. The effectiveness of modern fishing techniques (purse seines and long-lines), combined with increased fishing effort after World War II, led to declining ABFT catches and prompted the international community to develop a governance system that could regulate resource use. However, ICCAT's functioning has largely been characterized as an institutional failure mainly because of its inability to enforce catch limits and control the extraction rates of its member states (Hurry et al. 2008; Korman 2011).

Three distinct snapshots were coded into the database to reflect important variations in SES attributes (Epstein et al. 2014a). ABFT studies distinguish between Eastern and Western stocks because they differ with respect to breeding grounds, growth rates, and the relative size of the stock. The Western case is coded as a single snapshot from 1985 to 2007, reflecting the absence of dramatic shifts in state or policy variables during this interval. The Eastern case, which consists of stocks that breed in the Eastern Atlantic and Mediterranean, is coded over two separate time intervals, 1985–1995 and 2003–2007. The intervening eight year period reflects the gradual introduction of storage pens, or ABFT ranches, which were introduced gradually in the mid-90s but expanded ten-fold between 1997 and 2003 (Sumaila and Huang 2012). In both the Eastern and Western regions, the top-level actors are the ICCAT contracting parties, a group of nations that have signed and ratified an international convention to coordinate the science and management of tuna and tuna-like species in the Atlantic Ocean and Mediterranean. While ICCAT appears to have introduced a level of stability for the Western stock, the Eastern stock experienced declines between 1985 and 2007 and both stocks remain well below their historical peaks.

Indonesian forests

Indonesia contains the world's third largest tropical forest, with globally significant stores of carbon and biodiversity. Indonesia experienced rapid deforestation beginning in the 1960s, with the percentage of the country covered in forest dropping from close to 85% to <50% today.

Table 1: Continued.

Two distinct snapshots were analyzed in this case (Fleischman et al. 2014): From 1965 to 1998 governance was dominated by the dictatorship of President Suharto; after 1998 democratic governance and political decentralization were initiated, and deforestation rates first fell and then rose. For both time periods, the resource is forests, the governance system is the regime present during the time period; actors include large extractive industries and indigenous (adat) communities. From 1965 to 1998 the Indonesian forest governance system was dominated by the Indonesian central government with President Suharto at its center. Suharto maintained the political support of elites, particularly military officers, through dispensing patronage, often in the form of timber, mining and plantation concessions. In 1998, a new democratic constitution came into effect, which dramatically altered the formal structure of the central government, decentralized substantial amounts of power to district governments, formally recognized customary rights, and opened up new spaces for local political and economic entrepreneurs, as well as media and civil society actors to play a role. Additional actors thus emerged: district governments and local entrepreneurs. All data sources agree that deforestation rates fell dramatically in the immediate aftermath of the democratic transition, although it is not clear if this was due to policy changes or to the severe economic downturn that had triggered the fall of Suharto. After 2005, deforestation increased, however data sources differ on the extent of this increase, with FAO data indicating that deforestation remains substantially lower than during the Suharto era (FAO 2013), while independent remote sensing estimates show it rising to higher rates than those of the early 1990s (Hansen et al. 2013). See Fleischman et al. (2014) for further discussion of this uncertainty.

Montreal Protocol: ozone regulation

The Montreal Protocol – an international treaty to protect the ozone layer by phasing out ozone depleting substances – is generally credited as a successful example of international cooperation in response to a global problem. In the 1970s, scientists discovered the deleterious effect of chlorofluorocarbons (CFCs) that resulted in significant ozone depletion and the highly publicized ozone hole. The Montreal Protocol thus emerged out of a recognized need to reduce further impacts on atmospheric ozone. The Protocol is the most widely ratified treaty in the history of the United Nations. This case is comprised of two snapshots (Epstein et al. 2014b): (1) from the mid-1970s when the threat of ozone-depleting substances was first realized until 1989 when the Montreal Protocol was finally ratified; (2) the second snapshot runs from the ratification of the Protocol until its 25th Anniversary (2012). The major change between the two periods is the creation, development, and implementation of a governance system that manages the production and release of ozone depleting substances and, in the process, indirectly manages ozone. In the analysis, Epstein et al. (2014a) considered both ozone-depleting substances (the regulated externalities) and the atmospheric ozone layer (the public good) as "resources" governed by the Protocol. The actors are nation states, the Secretariat, and industry. The expected return to normal atmospheric concentrations of ozone as a result of the Montreal Protocol can at least in part be linked to attributes of the resources that facilitated regulation.

Rhine watershed

The Rhine is the largest watershed in north-western Europe, covering $170,000$ km^2 and a population of about 60 million across eight different countries (Huisman et al. 2000). The historical density of industrial and agricultural activity is among the highest in the world (Stigliani et al. 1993), and thus pollution in the watershed is a serious issue. There is a relatively long history of international cooperation to manage the Rhine: the earliest agreements were signed in the 19th Century, and focused on trade and salmon fishing. Pollution was not a concern until much later. By the 1960 pollution in the river had reached its peak, with salmon stocks depleted by 1960 and serious water quality issues in downstream sections of the river. Ultimately, a treaty for pollution control was signed in 1963, which resulted in the creation of the International Commission for the Protection of the Rhine (ICPR).

Table 1: Continued.

The case can be characterized by the following key components (Villamayor-Tomas et al. 2014). Two types of polluting resources are being managed: point-source pollutants like Cadmium or Zinc, and non-point source pollutants (e.g. nitrogen). Two snapshots comprise key governance systems: 1976–1986 as approval and initial implementation steps of the Chemicals Convention, and 1986–2000 as the adoption and implementation of the first edition of the Rhine Action Plan (RAP). An important difference between these two governance systems is the emphasis of the RAP on ecological outcomes in addition to previous objectives of pollution control and abatement. Finally, there are three clusters of actor groups: riparian nations, industrial users, and agricultural users. During the first time period, treaties provided a limited basis for collective action and pollution abatement, whereas during the second period, the RAP proved more successful. By the 1990s, pollution concentrations of a number of point and non-point source pollutants had been reduced to half of their levels in the 1960s, and the stocks of a number of aquatic species were on their way to full recovery (ICPR 2012).

described by Cox (2014), is a relational database which allows scholars to record information about the relationships between resources, governance systems, and actors within the context of a social-ecological system. The database includes over 200 variables measuring different aspects of social-ecological systems and is designed to facilitate cross-case analysis. This study focused on a limited subset of those variables.

Variables for this study were selected in two ways. First, we focused on Ostrom's (1990) design principles, as modified by Cox et al. (2010). This focus was chosen because these principles are supported by solid theory and abundant empirical evidence (Ostrom 1990; Agrawal 2001; Cox et al. 2010). The principles, discussed in greater detail below, include: *clearly defined boundaries*; *congruence between appropriation and provision rules and local conditions*; *collective-choice arrangements*; *monitoring; graduated sanctions; conflict-resolution mechanisms; minimal recognition of rights to organize; nested enterprises.* Second, we selected six other variables for the added insight they give to understanding how CPR theory translates to larger-scale systems. Two variables are considered important in the small-scale CPR literature but fall outside of the design principles – *dependence on the resources* and *group size/heterogeneity*. Two sets of factors have also emerged as important variables since the initial design principles were created – *external disturbances* and *resource characteristics*. Finally, two additional factors emerged from the analysis – *political power and civil society*, and *scientific knowledge*. While the accompanying case studies examine additional variables that were important in individual cases, these variables are not discussed in this paper because they did not appear to have broad applicability to the diversity of types of cases we examined.

In the case papers, the authors explore characteristics of governance, actor groups, and resources and their correlation with resource conditions. Data were obtained via a content analysis of journal articles. Primary sources (e.g. datasets and official documents) were also used when available. Coders worked

collaboratively, and controversial information and coding decisions were double-checked with external experts. Inferences about the relevance of variables were drawn in two ways. First, the authors conducted a series of within-case comparisons across actor groups, resource types and over time. Differences in variables across actor groups and/or resource types were checked against the effectiveness of governance systems. Similarly, changes in the characteristics of the governance system, actor groups or resource types over time were checked against changes in governance effectiveness and environmental outcomes. Second, we used process tracing, a within-case inductive technique that lays out, usually in a linear fashion, the course of events that connect causes and effects (George and Bennett 2005; Collier 2011). The emphasis on process enabled us to shed light on why and when some of those variables might be important and whether such importance was contingent on the simultaneous role of other variables.

In this paper, we synthesize the inferences made by the authors about the fourteen variables. We focus on the contribution of individual factors to the relative success or failure of the governance system over time in each case, following the conclusions reached in the corresponding paper on that governance system. Findings are derived from synthesizing the analyses carried out in each individual case study, and not from a formal comparative analysis. If the overall outcomes are poor but the case papers indicate that a factor contributed to improving the outcome, we rate that factor as a relative success. While the main focus of this paper is on how factors individually affect governance outcomes, we also note in the discussion that some of the factors co-occur and jointly influence governance outcomes in practice. However, due to space limitations, variable interactions will be considered in more detail in future work. Finally, although synthesizing was the main purpose of the paper, we also report some similarities and differences across the cases by grouping them according to salient characteristics such as the type of governance system, the sector and the transnational nature of the system. Coauthors from all five case studies contributed to this paper, thereby ensuring in-depth understanding of each individual case.

3. Results

3.1. Relative success in large-scale CPR governance

Our analysis reveals that in large-scale systems success is often partial or mixed. In contrast to early works of CPR theory which defined success on the basis of the existence of relatively long-lived institutions (e.g. Ostrom 1990), we analyze a broader array of outcomes, including both social and ecological variables. Furthermore, our cases cover 20–40 years, a shorter time period than some of the classic cases of long-enduring institutions. Three of our cases present well-known success stories: management of the Great Barrier Reef, pollution control in the Rhine River, and international regulation of ozone depleting substances via the Montreal Protocol. Yet, we find that these successes are incomplete: the Great Barrier Reef Marine Park has demonstrated significant improvements in

fisheries management and reef resilience but faces considerable threats from land-based pollution and climate change; the governance regime of the Rhine River has successfully alleviated point-source pollution but is less successful in resolving non-point source pollution and cleanup of river sediments; the Montreal Protocol has reduced the emissions of ozone depleting substances, but the residence time of these chemicals means that the ozone-related response remains to be seen.

The two remaining cases are less successful overall, although neither is an abject failure. Indonesia has some of the highest global deforestation rates and continues to be a center for illegal logging, but deforestation rates fell for a time after a new governance regime emerged in 1998, although they subsequently rose, and some sources indicate they may have returned to pre-reform levels. Similarly, the International Convention for the Conservation of Atlantic Tunas (ICCAT) has been widely criticized for its failure to restore tuna populations, yet the dramatic decline in Western stocks pre-dates the convention, which has subsequently managed to maintain that stock at stable, albeit low levels.

3.2. Design principles

In this section we address each of Ostrom's design principles, as modified by Cox et al. (2010), to evaluate the extent to which the presence or absence of the conditions described in the principle were associated with improvements or declines in resource condition. An overall summary of these evaluations is presented in Table 2. The text provides further nuance, noting, for example, when a factor may have contributed to improved governance even where the overall governance was poor.

1A. Clearly defined boundaries: Actors who have rights to withdraw resource units from the resource system are clearly defined.

The presence of clear boundaries has consistently been identified as an important design principle for successful collective action (Ostrom 1999, 2011). Ciriacy-Wantrup and Bishop (1975) suggested that the existence of boundaries was the fundamental distinction between open access and common-property regimes. We follow Cox et al. (2010) in subdividing the boundary principle to distinguish between the social boundaries of users and the physical boundary of the CPR itself.

The importance of clear social boundaries is moderately supported by all cases. In the Rhine River, the Great Barrier Reef Marine Park and the Montreal Protocol, clear identification of stakeholders and the assignment of rights and responsibilities were facilitated by well-defined institutional or administrative boundaries, which appear to have contributed to sustainable management. In the Great Barrier Reef Marine Park even the early governance system clearly defined who had withdrawal and other access rights. In the pollution cases, while early open access periods characterized by the absence of social boundaries were

Table 2: Summary of findings about design Principles from five case studies.

Design Principles		Indonesian Forests	Rhine River	Great Barrier Reef	Montreal Protocol	ICCAT
	1A. Clearly defined social boundaries	Contested	Present	Present	Present	Present
	1B. Clearly defined biophysical boundaries	Present	Present	Present	Present	Unclear for migratory species
	2A. Fit to local conditions	Inconclusive	Present	Present	Present	Absent as 'local conditions' not understood
	2B. Proportionality	Disproportionate benefits to central government	Present	Inconclusive	Present	Present but no clear effect on governance outcome
	3. Collective choice arrangements	Absent, then increasing after 1998	Absent but no clear effect on governance outcome	Absent but no clear effect on governance outcome	Present	Absent as governments represent users
	4A. Monitoring of ecological conditions and user behaviour	Weak ecological and user monitoring	Present	Present	Present	Weak ecological and user monitoring
	4B. Monitoring accountability to appropriators	Absent, then increasing after 1998	Substituted by other interest groups	Absent but no clear effect on governance outcome	Substituted by international agencies	Limited presence and knowledge contested
	5. Graduated Sanctions	Weak or Absent	Present for point, Absent for non-point source polluters	Present	Absent as existing mechanism is not applied	Weak or Absent
	6. Conflict-resolution mechanisms	Substituted by improved democratic system	Substituted by higher level negotiations and consensus	Present. Enhanced by legitimate judicial system	Substituted by higher level negotiations and consensus	Absent as high level negotiations highly contested
	7. Minimal recognition of rights to organize	Rights improving but remain weak	Present	Absent but no clear effect on governance outcome	Absent but substituted by involvement of major user in initial rule-making	Absent but substituted by lobbying
	8. Nested enterprises	Absent, then increasing after 1998	Present	Minimal considering the size of the system but no clear effect on governance outcome	Present but no clear effect on governance outcome	Present but no clear effect on governance outcome
	Governance effect	Continued Decline	Partial Improvement	Partial Improvement	Partial improvement	Continued Decline

correlated with high levels of pollution, the new governance systems provided greater clarity regarding emission rights, subsequently leading to lower emissions. Similarly, Indonesian forests initially lacked clearly-defined withdrawal rights, but a change in governance led to better defined boundaries, which in turn may be associated with modest improvement in resource condition. Nevertheless, improvements in outcomes were less pronounced than in the pollution cases, perhaps due to the incomplete and contested nature of those boundaries. Finally, while membership in ICCAT clearly defines the right to trade with other members, the conventions does not define withdrawal rights in non-member states and is at times poorly enforced within member states. Most case papers conclude that this principle is important primarily through its interactions with clear resource boundaries (principle 1B) and is dependent on other variables, notably monitoring and enforcement – principles 4 and 5.

1B. Clearly defined boundaries: The boundaries of the CPR are well defined.

Clear biophysical limits of (e.g. physical boundaries that delimit one resource system from another) and spatial boundaries defined by the governance regime (e.g. socially-constructed geographic regions) are both considered necessary preconditions to avoid open-access situations.

This principle is moderately supported by all cases. With the exception of Atlantic Bluefin tuna, all the resource systems studied have clear biophysical boundaries. The Rhine River, Great Barrier Reef, and Montreal Protocol cases also have clear governance-defined boundaries. In combination this boundary clarity has contributed to development of effective monitoring and governance in the Rhine and Great Barrier Reef cases; the effect is less clear for the Montreal Protocol where the boundaries are global in nature, encompassing the entire atmosphere. While biophysical boundaries are clear in the Indonesian forest case, governance-defined spatial boundaries are less so. In contrast, the biophysical boundaries of Atlantic Bluefin tuna stocks remain unclear and ICCAT has failed to define boundaries that correspond to the actual distribution of stocks. The effects of unclear boundaries on the general failure of ICCAT and Indonesian forest governance are difficult to disentangle from other attributes of these cases. It may be that these two dimensions of CPR boundaries may jointly influence successful governance, and this may explain why they have been conflated in previous research.

2A. Congruence between appropriation and provision rules and local conditions (congruence): Rules restricting where, when, how and how many resource units can be appropriated relate to local conditions.

The 'fit' or 'congruence' principle specifies the importance of matching rules to the characteristics of resources and resource users (Folke et al. 2007). The principle ensures that the governance response is appropriate to the magnitude and scale of impacts on the CPR system (Bohensky and Lynam 2005).

This principle is supported in four of the five cases, but seems to have the greatest importance in the fisheries cases. Fish are often mobile, exhibit chaotic

population dynamics (Acheson and Wilson 1996), and are distributed across a large spatial area. The 'fit' between the governance system and this dynamic resource unit is therefore particularly challenging. The expansion of no-take zones in the Great Barrier Reef Marine Park to improve protection of important fish stocks and habitats provides a good example of improving congruence between governance institutions and local conditions. In stark contrast, the governance of eastern and western Atlantic Bluefin tuna stocks is not congruent with current knowledge of their respective population dynamics, and may be contributing to overexploitation. In the pollution cases, widespread coordination matched governance actions to the scale of the environmental problem. This contributed to more efficient environmental and social monitoring and, in turn, to the relative success of pollution abatement efforts. Finally, the importance of this principle for the Indonesian forest case is inconclusive. The decentralization process aimed to align decision-making on appropriation rules with the scales at which harvesting was occurring, yet while deforestation rates did improve in the beginning of that period, they subsequently rose.

2B. Congruence between appropriation and provision rules and local conditions (proportionality): The benefits obtained by users from a CPR, as determined by appropriation rules, are proportional to the amount of inputs required in the form of labor, material, or money, as determined by provision rules.

Another dimension to this principle of 'fit' refers to how the costs and benefits of environmental governance are distributed within a group of resource users. It is often defined as the proportionality principle, as it invokes concepts of fairness and equity that match benefits to contributions.

The proportionality principle is supported in three of the five cases. However, the logic of proportionality differs between these cases. In international settings, such as the Rhine River and Montreal protocol, proportionality fostered rule formation and implementation: in both cases stalemates between perceived winners and losers were broken through agreements to re-distribute some of the costs and benefits, between upstream to downstream users in the Rhine River and between developed and developing countries in the Montreal protocol. By contrast, in Indonesia a lack of proportionality contributed to increasing deforestation. Because of the tax structure, timber taxes disproportionately benefit the central government, giving local governments an incentive to encourage conversion to agriculture or oil palm plantations, which have benefits proportioned more equally between central and local governments. The role of the proportionality principle in the Great Barrier Reef and ICCAT cases is uncertain. In the Great Barrier Reef, the existence of some discontent by commercial and recreational fishers points to issues related to the distribution of costs and benefits of the re-zoning plan. However, the discontent did not prevent approval of the plan and has not hindered its implementation. Ongoing, provisional rules are not tied to appropriation rules and benefits, again with little notable impact on governance outcomes. In the case of ICCAT, the influence of political bargains and lobbying on fishing quotas points to the interest of parties in minimizing differences between winners and

losers of fish restrictions. In a context of strong scientific uncertainty, however, those efforts did not lead to improved fish populations.

3. Collective-choice arrangements: Most individuals affected by the operational rules can participate in modifying those rules.

Ostrom (1990) argued that the ability of individuals affected by the operational rules to participate in modifying those rules was important for two reasons: first, it enhanced the legitimacy of those rules, thereby increasing the likelihood of compliance; and second, it facilitated adapting operational rules in response to changing local conditions. In our large-scale cases we interpret this principle to mean the involvement of resource users in modifying operational rules directly or through legitimate representation.

Support for the collective choice principle in these cases is mixed. The Indonesian forest and Montreal protocol cases support the principle. In Indonesia, a strong, centralized dictatorship prevented user participation in governance. Reforms after the collapse of this government in 1998 increased public participation in decision-making, and these changes may be associated with improved outcomes, although this is not certain. The Montreal Protocol created a framework for decision-making that involved both member states and large industries, and this collaboration is associated with the success of the treaty. By contrast, in the Rhine and Great Barrier Reef cases, most affected stakeholders did not participate directly or indirectly in collective choice situations, yet governance has been successful. In both cases collaborative arrangements between other interested parties may mitigate the absence of collective-choice arrangements. In the Rhine case, countries have reached collaborative agreements with large polluting firms but not with other resource users, such as farmers. In the Great Barrier Reef Marine Park national and state government collaborate formally. User groups are consulted in policy and institutional change but decision-making power remains with management actors. In ICCAT member states negotiate resource limits, quota shares and institutions at the international level on behalf of their industries, but the resource users themselves have limited opportunity to participate. This parallels system failure, but whether it contributes to it directly is inconclusive – in fact, it could be argued that nations working on behalf of their fishing industries have been major contributors to governance failures.

4A. Monitoring: Monitors are present and actively audit CPR conditions and appropriator[1] behavior.

Monitoring is one of the design principles that has received the most support in subsequent literature (Coleman and Steed 2009; Cox et al. 2010; Tucker 2010). There are two distinct aspects of monitoring – monitoring of resource conditions and user behavior. Monitoring of resource conditions is necessary for the

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[1] An appropiator is a person who extracts resources from a system.

governance system to adapt to new conditions, and monitoring of user behavior is vital for enforcement of rules.

Both types of monitoring are supported in the cases, but to different degrees. Monitoring of resource conditions is strongly tied to outcomes – the three cases that had strong ecological monitoring, the Great Barrier Reef, Montreal Protocol, and Rhine River, display the best outcomes. In each case, information from monitoring has clearly been used to improve the governance system over time. By contrast, the ICCAT and Indonesian forest cases had weaker ecological monitoring systems, and displayed poorer outcomes. Furthermore, recent improvements in ecological monitoring in Indonesia may correlate with lower deforestation rates. Monitoring of user behavior, however, was weakly tied to outcomes. For the Indonesian forest and ICCAT cases, weak monitoring of users appears to contribute to poor outcomes, while for the Montreal protocol case, monitoring by the UNEP secretariat appears to contribute to high levels of compliance. In the Great Barrier Reef Marine Park monitoring of users is extremely challenging. There is some evidence of non-compliance in no-take zones, but overall fisheries outcomes have improved (McCook et al. 2010). In the Rhine River case, farmers are not monitored but large firms self-report discharges, and this system is related to improvements in point-source pollution.

4B. Monitoring: Monitors are accountable to or are the appropriators.

Many studies of small scale CPRs emphasize the importance of local monitors who are accountable to or are the appropriators (Persha et al. 2011; Chhatre and Agrawal 2008). Without this accountability, it is argued that monitors may act in the interest of external actors who favor destruction, rather than sustainability of the resource. It is not clear from the theory how this principle will apply at large scales where accountability relations are complex.

This principle is not clearly supported by any of the five large-scale cases under study. In all cases, monitoring is primarily a function of government agencies that are at best distantly accountable to resource users, yet several cases show that this kind of monitoring has successfully contributed to sustainable resource use. As is the case with the principle on collective-choice arrangements, it appears that other types of actors may be able to fill the role played in small scale CPRs by appropriators. For instance, in the Rhine River organized interest groups such as Dutch farmer associations, environmental groups, and waterworks associations, as well as industrial groups, play an important role in monitoring. In the Great Barrier Reef Marine Park, a number of agencies are involved in ecological and user monitoring including the Marine Park Authority, Queensland's state government, and the Australian Institute of Marine Science. Within the context of a broader democratic governance framework, these agencies are indirectly accountable to the electorate. In the Montreal protocol, all monitoring is done by international agencies. In Indonesia, improvements in deforestation rates have been associated with three shifts in monitoring: empowerment of local communities, improved government oversight, and an increasing role for international and civil society

actors concerned with the environment, although the extent of improvement is inconclusive. Finally, monitoring of Atlantic Bluefin tuna populations and harvesting rates is carried out primarily by national and international government agencies. Yet, in this final case monitoring of resource status and users has not led to improved outcomes primarily because the knowledge generated by monitoring is contested in political arenas.

5. Graduated sanctions: Appropriators who violate operational rules are sanctioned according to the context, seriousness and frequency of the offense.

Sanctions are another one of the design principles that have received considerable support in subsequent studies (Coleman and Steed 2009; Cox et al. 2010). Sanctions help ensure compliance in a variety of ways including economic deterrence (Becker 1968). Graduated sanctions, which increase with the severity and frequency of violations, can ensure flexibility to punish repeat offenders without creating a draconian, and therefore illegitimate, governance system (Ostrom 1990).

Evidence for the importance of sanctions is mixed in the five cases. For ICCAT and the Indonesian forest cases, weak or absent sanctioning mechanisms are associated with poor outcomes. Similarly, in the Rhine River case, sanctions are applied to point-source polluters and not to non-point source polluters, explaining the disparity in their outcomes. In the Great Barrier Reef Marine Park differential sanctions exist and can be considerable for severe offences. However the extent to which non-compliers are detected and prosecuted and by extension the influence of sanctions on compliance is uncertain. The Montreal protocol contains a trade sanctioning mechanism, although it has never been used and yet compliance with the Montreal protocol is high. We could not find specific evidence of graduated sanctions clearly influencing governance outcomes in any of the cases. It is not clear if this is because graduated sanctions are less important at larger scales or because analysts of large-scale situations have not been attentive to their existence.

6. Conflict-resolution mechanisms: Appropriators and their officials have rapid access to low-cost arenas to resolve conflicts among appropriators or between appropriators and officials.

According to Ostrom (1990) the existence of low-cost conflict resolution mechanisms is essential because they enable appropriators and officials to resolve conflicts that are the result of ambiguity in rules without having to renegotiate or challenge the rules.

Clear evidence in support of this principle was not found in the cases. However, in some of the cases the political contexts and negotiation strategies adopted by actors imply the presence of *de-facto* mechanisms of conflict avoidance or resolution. For instance, in the Great Barrier Reef Marine Park sanctions are adjudicated through a well-functioning judicial system. The European Union and member countries may provide similar conflict resolution venues for the Rhine River case. In Indonesia, while the previous Suharto regime broadly suppressed conflict, the developing democratic institutions in

the country now provide some measure of conflict resolution, and this may be associated with better outcomes. Finally, in all three international cases, international negotiations resulted in agreements. In the Rhine River and Montreal Protocol these negotiations helped resolve previous stalemates and essentially led to the emergence of the current governance regime. In contrast, ongoing, annual negotiations within ICCAT over the assignment of fishing quotas are associated with poor governance outcomes.

7. Minimal recognition of rights to organize: The rights of appropriators to devise their own institutions are not challenged by external governmental authorities.

According to Ostrom (1990), resource users must be able to design at least some of their own rules without being undermined by higher-level authorities. This has been found to be particularly important considering the prevalence of top-down approaches to environmental governance and the long history of governments undermining local rights to resources (Bromley 1991). However, at large scales it is not always clear how this principle differs from participation in collective choice processes (principle 3).

In only one of the cases we studied do appropriators or polluters have clear recognition of their rights to organize, while in the other four cases, these rights are attenuated. Polluters in the Rhine River case have the right to organize politically and, using market-based instruments, have a measure of autonomy in devising abatement rules and targets. In contrast, while fishers in the Great Barrier Reef Marine Park can and do organize politically and are consulted in fisheries policy, they do not create their own rules, yet governance is successful. Polluters are not granted autonomy in the Montreal protocol case, although DuPont did play a key role in initial negotiations. In Indonesia, formal rights of most individuals and groups to organize politically were not recognized until after the fall of Suharto, and despite enhanced autonomy these rights remain weak with ambiguous effects on forest management. Finally, in the ICCAT case fishers lack the right to design institutions but they do organize to lobby their respective representatives. In all, adherence to this principle does not map well onto resource governance outcomes, and may indicate that it is less important in large-scale cases.

8. Nested enterprises: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Ostrom (1990) argued that because of the nature of environmental problems, even local governance systems needed to be nested within higher-level governance structures. In large-scale systems this principle may be expected to be even more critical.

The evidence for this principle is mixed in our five cases. Decentralization of forest management in Indonesia was initially associated with decreased rates of deforestation, indicating that a movement away from centralized management

towards a more nested system may favor sustainable management, although it remains unclear why this improvement was not sustained. In the Rhine case, nesting national and international (i.e. European Union) regulatory frameworks also appears to have contributed to success. On the other hand, ICCAT, which, like the Rhine, nests national regulatory frameworks within an international treaty, is largely a failure. Governance of the Great Barrier Reef Marine Park reflects a somewhat centralized or highly streamlined polycentric system considering the size of the Reef but has achieved some significant results. Yet governance of the broader catchment is less successful despite multiple organizational layers. In the Montreal protocol case, the presence of nested enterprises was not seen as an important contributor to success. In the Indonesian, Rhine, and Montreal cases, civil society groups appear to offer a kind of horizontal interplay that may have contributed to the improvement of governance regimes.

3.3. Other important variables

In this section we analyze six additional variables that have either been the focus of research in local-scale commons governance or which emerged from the comparative analysis of the cases presented here. This is not intended to be an exhaustive study of all potentially important variables from CPR theory (e.g. see Agrawal 2001). Instead, it aims to be suggestive of where future research on large-scale social-ecological systems can be most productive. Findings from this section are summarized in Table 3.

Resource Dependence: In many small-scale CPR systems users are dependent on resources for their subsistence and livelihood needs. High resource dependence can tie resource users into unsustainable patterns of resource use i.e. where poverty forces people to over-exploit resources. Conversely, where tenure is well-defined, high resource dependence can promote stewardship of resources (Ostrom 1990).

　　Four of our cases support the notion that high dependence fosters over-exploitation. In the Indonesia forest case both local user groups and state actors are considered to be heavily dependent on forest resources, with the economic dependence of state actors in particular driving higher levels of deforestation in the older governance regime. Similarly, state members of ICCAT, in representing the interests of their fishing industries, which are incentivized by the high economic value of the fishery, have lobbied strongly to increase extraction limits thereby contributing to governance failure. In the Great Barrier Reef Marine Park, commercial fishers are economically and culturally highly dependent on reef fisheries and recreational fishers claim high cultural dependence. These high levels of dependence were used to argue against the expansion of no-take zones and reduced access to fisheries. The re-zoning of the marine park went ahead but cost the Australian government over AU$250 million in compensation to economically-dependent businesses. In the Ozone case, economic dependence on ozone depleting substance production was mitigated by breakthroughs in

Table 3: Summary of findings of other variables that may contribute to governance success at large scales.

Governance principles	Indonesian Forests	Rhine River	Great Barrier Reef	Montreal Protocol	ICCAT
Resource dependence	Present. Fostered unsustainable resource use	Present. Fostered resource stewardship	Present. Fostered unsustainable resource use	Present. Fostered unsustainable resource use	Present. Fostered unsustainable resource use
Small group size and homogeneity	Present	Present	Present	Present	Heterogeneous interests and identities
External disturbance	Present but no clear effect on governance outcomes	Present	Present	Absent	Absent
Governable resource characteristics	Present	Absent as long residence times of organic pollutants	Present	Absent as long residence times of Ozone Depleting Substances	Mixed contributing to differential governance outcomes
Legitimate political context and participation by civil society	Absent in first period, increasing but still low in second period	Present	Present. Substituted by broad political legitimacy	Present	Inconclusive
Scientific knowledge	Absent	Present but effect on outcome is weak	Present	Present	Contested
Governance effect	Continued decline	Partial improvement	Partial improvement	Improvement	Continued decline

technological substitutes. In only one case did high dependence on resources foster stewardship of resources. In the Rhine River case, increased appreciation of the river's ecological and cultural values contributed to strong remedial action against polluters. At large-scales higher numbers of actors are dependent on the resource system in different ways, which complicates how this variable influences governance outcomes. However, our cases suggest that high resource dependence, in particular economic dependence, tends to promote unsustainable resource use in large-scale systems even where poverty is not an issue.

Group Size and Homogeneity: The size and homogeneity of groups has been a mainstay of the collective action literature since Olson (1965). Empirical studies are far from unanimous but suggest that group size and homogeneity have both direct and indirect effects on collective action (Agrawal and Yadama 1997; Vedeld 2000; Agrawal and Goyal 2001; Poteete and Ostrom 2004). In general, it is hypothesized that groups are more likely to resolve a collective action problem when they are small, share common interests and identities, but are heterogeneous in terms of wealth and endowments.

Compared to small-scale systems, our cases could all be considered to have large numbers of actors. Despite this, three of our cases show improved governance outcomes, while the remaining two show continued decline in resource status but improvements on previous governance regimes. In three cases actor groups are considered to be relatively homogenous – Montreal Protocol, Rhine and Great Barrier Reef – and this correlates with positive governance outcomes. By contrast, in the ICCAT case which focused on the attributes of member nations, heterogeneity of interests and identities were argued to be contributing to the lack of improvement in Atlantic Bluefin tuna stocks. Heterogeneities include variability in political systems, regulatory regimes, culture, wealth and interests (i.e. consumption vs. production). In fact, Japan as the overwhelmingly dominant market for tuna products begins to approach a *de facto* veto player in negotiations, demonstrating the extent of power heterogeneity in this case. Similarly, in the Indonesian forests actors with interests in forest conservation were, until recently, isolated from each other, while the Suharto regime was successful at organizing forest exploiters into a small group with homogenous interests. It is notable that governance outcomes are improving in systems defined by large numbers of actors, particularly where these actor groups appear relatively homogenous. However, assessing the effects of group characteristics is challenging in large-scale systems in that observed effects could be artifacts of the way in which actor groups are defined in each case. For instance, the Montreal protocol and Rhine cases define Nation States as governing actors and industry as the 'users' rather than considering individuals, while the Great Barrier Reef case considers commercial fishing sectors as one group of actors but individual recreational fishers as another group of actors.

External Disturbances: Contributors to CPR theory have only recently started focusing on the effects of disturbance on local resource governance (Anderies et al.

2004; Cox and Ross 2011; York and Schoon 2011). Some argue that disturbances may increase the salience of cooperation (Plummer and Fitzgibbon 2004).

Two of the five cases support the hypothesis. In the Rhine River case, the emergence of collaboration among national governments was partially triggered by ecological disasters. In the Great Barrier Reef case, commitment to the 1999–2004 re-zoning program was strengthened by the occurrence of a tropical cyclone and mass coral bleaching events. In contrast, in the Indonesian forest case disturbances exist (e.g. droughts and fires related to El Niño, economic crises, and the fall of Suharto's government in 1998), but there is no clear link to responses by the governance system. It is possible that the decline in deforestation observed after 1998 was caused by the economic crisis, but this is uncertain. Overall, it appears that the occurrence of external disturbances is not usually sufficient to trigger or sustain cooperation among actors in large-scale systems. Policy entrepreneurs and authorities with a stake in resource conservation seem to be a necessary condition to convert disturbances into opportunities to strengthen governance.

4. Resource Characteristics (productivity, renewability, and mobility)

Resource characteristics, while not the focus of most CPR theory, are nonetheless an important influence on the effectiveness of management (Agrawal and Goyal 2001; Agrawal 2003). For natural resources, three aspects of resource characteristics and their relationship with sustainable governance have been studied in detail: productivity, renewability, and mobility. Productivity is the rate at which biomass is produced, and is usually considered for ecosystems (rather than resource units). Renewability refers to the doubling time of a resource being managed, and mobility is the extent to which the resource moves.

Evidence for the importance of these resource characteristics is mixed in the five cases. In the cases of Indonesian forests, Great Barrier Reef, and Bluefin tuna, renewability of the resource being managed appears more important than productivity of the resource system. Fish targeted by fishers in the Great Barrier Reef Marine Park are renewed more quickly than corals, a possible contributing factor to the recovery of fish stocks following expansion of the network of no-take areas. Similarly, the high rate of renewability of selectively logged forests in Indonesia may contribute to decreasing the severity of deforestation. For Bluefin tuna, the western stock has a slower renewal time than the eastern stock, which likely contributed to the large declines experienced in the 1970s and the continued failure to recover to historical levels. Resource mobility affects vulnerability of resources in several seemingly conflicting ways. Resources that are sessile, such as trees and corals, can be more vulnerable to exploitation because appropriators know where to find them, and because persistent external factors can cause degradation (e.g. nutrient runoff and sedimentation for corals). However, being sessile makes monitoring of the resource much easier. On the other hand, highly mobile resources, such as Bluefin tuna, are extremely challenging to monitor.

Prior to development of technologies that facilitated exploitation (e.g. GPS, sonar, spotter planes), the mobility of Bluefin tuna might have served as a buffer from overexploitation. Yet with the advent of sophisticated technologies, coupled with the high price of Bluefin tuna, this is no longer the case. Thus, overall, resource characteristics appear to be important, but can be manifest in different ways and interact with other aspects of social-ecological systems.

The pollution cases present an additional layer of complexity as they include both a naturally produced resource (i.e. ozone and water quality); and a pollutant (i.e. ozone depleting substances, organic and inorganic pollutants) that undermines natural processes. For pollutants, productivity can be interpreted as the rate at which pollutants are released into the environment, renewability as the residence time of a pollutant (i.e. how long it remains in the resource system before coming non-toxic), and mobility as the spatial extent of spread of a pollutant. Ozone depleting substances are highly mobile with long atmospheric residence times which have contributed to the persistence of ozone depletion despite declining production. Organic pollutants in the Rhine case are also mobile and continue to be produced from non-point sources at high levels; but cutbacks in point source production combined with shorter residence times have led to improved water quality. In sum, these large-scale pollutant cases appear to demonstrate that individual attributes of a pollutant explain little in terms of environmental outcomes in the absence of additional attributes.

Political context and civil society: Rather than emphasizing local organization, as in CPR theory, our cases point to the importance of the wider political context through legal rights for broad classes of actors, levels of political organization within and between actors, and the importance of non-governmental organizations at various levels. At large scales, civil society organizations may act as important mediating forces between the decision-making process and those affected by the operational rules, while participation in decision-making and the legitimacy of those decisions may be mediated by broader political trends – such as the legitimacy of the overall governance system.

Four cases highlighted the importance of these variables. Both the Montreal protocol and Rhine River cases discussed the importance of civil society in putting pressure on international decision-makers to take action. Civil society organizations have also begun to play an important role in the Indonesian case since the fall of Suharto. Both the Indonesian forest and Great Barrier Reef cases also discuss the role of differential levels of political power. Under the centralized Suharto regime, a small group of oligarchs possessed the power to suppress all political opposition – enabling the regime to effectively exclude all other actors from formal decision-making. This correlated with very high extractive pressure. Political opening after 1998 led both to increased civil society monitoring of extraction and a more complex system of corruption around timber harvests, which may have contributed to both an initial decline and a subsequent rise in deforestation. In contrast, in the Great Barrier Reef case, while decision-making

power rests with management agencies, on the whole rules are generally complied with (although there is some evidence of non-compliance). This could be the result of widespread awareness campaigns encouraging stewardship alongside the perception that the governance institutions have broad political and social backing across Australia. Further research is needed to understand the role of the wider political context in large-scale governance.

Scientific Knowledge: Studies of small-scale CPRs have emphasized the importance of local or indigenous knowledge for sustainable management (e.g. Gadgil et al. 1993; Berkes 1999; Olsson and Folke 2001). In our large-scale cases, scientific knowledge appears to be important. In two cases, the Great Barrier Reef and Montreal protocol, scientists played crucial roles in discovering problems, galvanizing public awareness, proposing and advocating for solutions, and building consensus. It is not clear what factors enabled scientists to achieve a consensus on the nature of the problem and the actions to be taken. The role of scientific knowledge was less crucial in the Rhine River, although long-term ecological monitoring provided a basis for agreement about the nature of problem. In stark contrast, despite decades of research, scientific knowledge about the relationship between seemingly distinct Atlantic Bluefin tuna stocks remains hotly contested, and scientific advice about fishing levels is routinely ignored and/or manipulated. The role of scientific knowledge in governance of the Indonesian forest case seems relatively minor, as it is not clear how scientific understanding contributed to better outcomes. It is unclear why scientific advice was followed in the Great Barrier Reef and Montreal cases, while it was not in the ICCAT case. Thus, it is not clear how this variable interacts with other conditions to co-produce outcomes.

4.1. Comparing across different types of cases

The cases included in this paper are different in a number of crucial aspects such as the sector, time-periods, environmental problems, etc., which make systematic comparative analysis challenging. In this section we make some observations based on non-systematic comparisons between cases with similar characteristics, with the goal of generating hypotheses that can be explored in further sector-specific research. Thus, we first compare the least and most successful cases. Second, we compare the international cases with the others. Third, we consider differences in the outcomes of our fisheries cases, and contrast important variables in the pollution cases.

We find that the least successful cases (ICCAT and Indonesian forests) share the absence of three design principles: clearly defined social boundaries (1A), monitoring (4A), and nested enterprises (8). They also differ on key variables, suggesting multiple pathways to poor outcomes. For instance: the absence of collective-choice mechanisms was strongly associated with deforestation in Indonesia but only weakly linked to outcomes for Atlantic Bluefin tuna; the

existence of multi-level governance was immaterial in the ICCAT case, but its emergence in Indonesian forest management may be associated with small improvements in deforestation rates, finally; the lack of fit between governance institutions and the resources they are designed to govern explained failures in ICCAT, but had mixed results in Indonesian forests.

The more successful cases share the combined presence of three design principles: clearly defined social boundaries (1A), monitoring (4A), and fit to local conditions (2A). All three cases also have clearly defined biophysical boundaries (1B), although the implications for outcomes are less clear for the Montreal protocol due its global nature. The absence of collective-choice arrangements was notable in two of the three success cases, contrary to CPR theory. Yet, it is suggested that in both the Rhine River and Great Barrier Reef cases, other political dynamics may have substituted for 'user' participation in decision-making. As above, successful cases also differ in some key variables reiterating the absence of panacea or one-size-fits-all solutions to environmental governance (Ostrom 2007). For instance, accountability of monitors to appropriators (4B) and rights to organize (7) were present and influential in the Rhine River case, but were absent with minimal effects on outcomes in the Great Barrier Reef and Montreal protocol cases.

All three international regimes (ICCAT, Montreal protocol and Rhine River) lacked sanctioning mechanisms between countries. Nevertheless, two of them achieved significantly improved outcomes. This finding is consistent with legal scholarship, which suggests that it is difficult to align the principle of national sovereignty and international authority (e.g. Birnie et al. 2009). This design principle may, therefore, need adapting to international settings. By contrast, group heterogeneity seems to be more salient in international scenarios. There are two plausible reasons. First, international cases naturally involve more diversity than national cases, if only because state boundaries tend to reinforce cultural and political differences as well as in-out group dynamics. Second, international cases often require the creation of new communication and cooperation structures, which often involves prolonged bargaining, rendering differences of interests more salient to the actors involved.

In the fisheries cases, as compared to the non-fisheries cases, clear biophysical boundaries and congruence between rules and local conditions emerged as particularly important. Our analysis suggests that these principles strongly influenced the different trajectories of the ICCAT and Great Barrier Reef cases but played a relatively minor role in the other three large-scale CPRs. It is possible that the mobility of fish in coastal and ocean systems make the definition of biophysical boundaries and the creation of matching governance institutions particularly challenging, but also particularly important for outcomes. This contrasts with the fairly static or bounded biophysical boundaries of forests, rivers, and the earth system.

Finally, in the pollution cases the proportionality between the cost and benefits of cooperation was found to be particularly relevant. In cases of pollution there

is often strong asymmetry between polluters and those who bear the negative externalities of pollution. This situation is different from classic appropriation scenarios where all members of a group of users share similar private benefits and costs of over-appropriating the resource. In atmospheric pollution cases like the Ozone, polluters bear the costs of pollution but these are minimal compared to the private benefits they obtain from their emitting activities. In river pollution cases like the Rhine, upstream polluters can avoid bearing any costs of pollution. In these scenarios it is challenging to fully internalize the pollution externality by making polluters pay for its full cost. Thus, the ability to negotiate a fair allocation of said costs can be central to the success of the governance system. Indeed, in both the Montreal protocol and Rhine River cases, the ability of stakeholders to distribute the costs of pollution abatement in a way that satisfied polluters and non-polluters seems to have played a critical role in determining outcomes.

5. Discussion

The results presented above provide the basis for developing a series of propositions and questions about the applicability of CPR theory to large scale social-ecological systems.

Our results from synthesizing findings across these five cases suggest that two conditions may consistently play a role in the success or failure of large-scale social-ecological governance: clearly-defined boundaries and monitoring of resource conditions. Other variables played a role in important subsets of cases: fit to local conditions was present in all successful cases, while a lack of nested governance arrangements was associated with failures, but these variables did not yield consistent findings across the remainder of cases. Other variables, such as sanctioning mechanisms, have less clear results. This second set of findings can be interpreted as a hint of multiple conjunctural causation (Ragin 1989; Berg-Schlosser et al. 2009), according to which both the presence and absence of a condition (i.e. the conditions that vary across our cases) can lead to success or failure, depending on the values of other conditions. Further research into large-scale social-ecological systems can illuminate the implications of this argument and the importance of those variables through three research priorities. First, since all of these variables are the results of prior collective action, research identifying enabling conditions for the emergence of these two conditions would help illuminate the process through which large-scale resource management dilemmas can be ameliorated. Second, researchers should search for cases which show success but lack one or more of these two characteristics, in order to further illuminate the ways in which these variables interact to influence outcomes. Third, the international regimes examined in this paper all had relatively weak sanctioning mechanisms, yet two were quite successful. Further research is needed to understand how these successes were achieved in spite of weaker sanctioning regimes.

Our results also suggest that three conditions emphasized in the small-scale CPR literature need reconceptualization to apply to larger systems. These are

accountability of monitors to users, the ability of resource users to participate in making collective choice decisions, and the recognition of the rights of users to self-organize. All three of these focus on the ability of resource users to self-organize. Bottom-up self-organization may be difficult or impossible to achieve in large-scale systems, and thus other dynamics may be necessary. However, with only five cases it is difficult to determine whether bottom-up self-organization is possible. Further research is needed to search for large-scale cases which may exhibit bottom-up user self-organization, and to identify whether these design principles hold for that subset of cases. Furthermore, conceptual development is needed to understand how large-scale governance systems work without the types of accountable monitors, user involvement in collective choice, and recognition of rights to organize that are found in small-scale cases.

The data from our case studies are suggestive of how successful large-scale governance systems achieve the public legitimacy, information flow, and effective monitoring that are facilitated at small scales by accountability of monitors to users, participation in making collective choice decisions, and the right to organize. Two factors emerged as particularly important in our cases: first, legitimacy, information flow, and effective monitoring may be facilitated by aspects of large-scale political system that encourage broad participation, including an active civil society and the presence of broadly representative and legitimate political system. Second, the existence of a scientific consensus and of active environmental monitoring was strongly associated with effective problem solving, implying that at large scales, science may play a crucial role in solving resource dilemmas. The exact role of these two factors, and how the interact with the other variables discussed in this paper are not yet clear, and should be a focus for further investigation.

6. Conclusion

6.1. Validation of the design principles

Comparing the five cases shows varied support for the eight design principles (see Table 1). This directly contradicts recent claims that the design principles are not applicable at large scales (e.g. Araral 2014). Clearly defined social and physical boundaries (principles 1A and 1B) and monitoring of CPR conditions (and to lesser degree user behavior) (principle 4A) were important in all five cases – explaining both relative success and failure. Graduated sanctions (principle 5), fit to local conditions (principle 2A), and (implicit) conflict-resolution mechanisms (principle 6) also received strong support, in four of the five cases. Proportionality (principle 2B), collective choice arrangements (principle 3), and nested enterprises had moderate support (in 2-3 cases each). Whereas, accountability of monitoring to resource users (principle 4B) was not supported in any of the five cases, while minimal recognition of rights to organize (principle 7) was only supported in one case. Overall, the results are somewhat similar to those of Cox et al. (2010), which found strong support for principles 1A, 2A, 2B, 4B, and moderate support for principles 1B, 3, 4A, 5, 6, 7, and 8.

Our results offer support to certain design principles but also highlight differences in their application to small-scale versus large-scale systems. In particular, we suggest that the weak support of principles 4B and 7 could be explained by the scaling up of governance. This is clearest in the case of 4B, which establishes the need for self-monitoring by users or accountability of monitoring to resource users. In large-scale systems, states and international bodies act as monitors thereby altering the direction of accountability. In our cases we found that involvement of other actors, including civil society actors, may substitute for resource users in ensuring an appropriately motivated monitoring system. Further research is needed to clarify how political dynamics and civil society play a role in these accountability relationships.

6.2. Interactions between principles

Interactions between principles were also found to be important in several cases. Clearly defined physical and social boundaries were supported across all five cases and interacted closely with ecological and social monitoring (principle 4A), accountability of monitors to resource users (4B), and sanctioning (principle 5). We also found that several of the design principles interacted with other governance variables, like political dynamics and civil society, and resource characteristics. For instance, civil society organizations were crucial in promoting monitoring, sanctioning, and rule-making in several cases (Indonesia, ICCAT, Montreal). Similarly, political dynamics compensated to some extent for the absence of collective-choice arrangements and influenced the proportionality of costs and benefits (Indonesia, Great Barrier Reef). Resource characteristics also mediated the effects of other variables. Both the size and mobility of the resources systems and units influence the ease of monitoring and of matching governance institutions to resource dynamics. These complex interactions among variables make it difficult to identify strong causal relationships between design principles, governance variables and outcomes.

6.3. Limitations and future research

One key challenge of comparing the design principles across cases is that Ostrom (1990) presented them as being neither necessary nor sufficient conditions for sustainability, but rather as empirically observed regularities in successful cases. A finding that a design principle is present in an unsuccessful case, or absent in one that is successful, is thus not definitive evidence that the principle is wrong. Instead, we argue that our large-scale cases indicate multiple pathways to both success and failure that, in different contexts, are dependent on different configurations of variables.

Our analysis was based on a small sample of cases, which only allowed for an informal qualitative comparison across different SESs. We compared our research findings to the general expectations of CPR theory by comparing the results of the 5 cases to CPR theory both on an individual basis and by grouping

them around salient variables. Given the large number of causal conditions under investigation, more cases are needed in order to perform either Qualitative Comparative Analysis (QCA – see Schneider and Wagemann 2010 for a discussion of the limits of QCA in small samples) or to perform quantitative assessment of design principles and other variables. Building a larger compilation of cases of for large-N comparisons is the goal of the SESMAD project. With this database, researchers will be able to develop meta-analyses of many cases. These analyses will permit deeper comparisons of the operation of design principles across different cases, such as between fisheries and forestry resources, as well as the different configurations of variables that influence the sustainability of the governance systems.

More broadly, analysis of large-scale systems is constrained by a lack of examples of large-scale governance globally (as compared to empirical research on small-scale systems), and a dearth of research on some of the factors considered. For instance, conflict resolution mechanisms have not been directly researched in any of the cases. We found that for many of the variables considered in this issue, more empirical research is needed to understand the mechanisms by which these factors influence governance outcomes, and interact with each other.

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